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16. Abstract Evidently, there is now no obvious need to justify the pressing nature and promise of the problem of creating a human biological life support system (BLSS) applicable to future problems of cosmonautics. At present, there is no doubt of the anticipation of a significant increase in the length of space flights and in the number of people who participate in space investigations.			
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## Biological Human Life Support Systems

(A Survey of Investigations in the USSR)

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Evidently, there is now no obvious need to justify the pressing nature and promise of the problem of creating a human biological life support system (BLSS) applicable to future problems of cosmonautics. At present, there is no doubt of the anticipation of a significant increase in the length of space flights and in the number of people who participate in space investigations.

It is interesting to note that the first predictions that were made relative to using biological methods for creating a habitable environment in spacecraft were made at the end of the last century, i.e., when there was still no foundation for concepts about the reality of artificial satellites of the Earth, and still more, about manned space flights. These predictions were made by K. E. Tsiolkovskiy (1883) and were first published by him in 1903. It is also known that one of the founders of rocket building in the USSR, F. A. Tsander, performed experiments in 1915 on growing plants in wood charcoal and using the products of human vital activity for their nourishment. These were evidently the first experimental-ecological investigations performed in the interests of creating BLSS.

This significantly intuitive period in the development of scientific thought in the field of space biology we are interested in, if it did not in fact produce direct results, then did play an extremely important role in the ideological preparation of the discussed problem, when artificial satellites of the Earth became a reality in 1957 and initiated the era of human space activity. At this time, the question of creating a life support system for space crews based on the biological cycle of substances was immedi-

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\* Numbers in margins indicate foreign pagination.

ately transformed from a scientific idea into a practical problem as an alternative to systems based on a supply of the substances consumed by man.

For a number of reasons which developed historically, the solution to this problem immediately took the pathway of creating BLSS based on one-celled algae. The first theoretical calculations of such systems were undertaken by American scientists in the 1950's and the first experiments in supporting animal gas exchange with algae photosynthesis were performed (chlorella).

In the Soviet Union, similar animal experiments up to 12 days long were performed in 1960-1961. The absence of signs of a toxic effect of the atmosphere regenerated by chlorella enabled us in 1961 to perform certain experiments on human gas exchange support. These experiments demonstrated the practical possibility of directly coupling man and chlorella, at least in short-term experiments. Subsequent experiments involving human gas support exchange performed in the USA (at the Boeing and General Electric firms) in 1962-1963 also had precisely the same results.

Analysis of the results of this empirical period of testing the creation of algae-based BLSS demonstrated the insufficient level of knowledge and the insufficient scientific justification of making such attempts at that time. It became clear that the problem of creating human BLSS cannot be effectively solved on the pathway of empirical attempts without the preliminary investigation of the limiting, intermediate problems, and without taking into account the scientific essence of the BLSS problem itself, which is obviously in the sphere of ecology and general biospheric studies. We concluded that the problem consists primarily in investigating certain general functional principles of quite stable artificial ecosystems, and then already in the development of the practically operating human life support systems for spacecraft,

with their inherent limitations. In other words, the creation of practical BLSS should be viewed as the partial result of developing a more general, and significantly, new scientific trend in ecology -- the ecology of artificial (anthropogenic) ecosystems.

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A natural result of the first period of investigations was the necessity of developing a strategy and structure of the investigations which would derive from the scientific essence of the problem and the structuro-functional organization of the natural original, whose basic laws of existence could be used when creating BLSS.

A large number of problems that were frequently independent remained to be solved in order to justify the choice of biological objects, to study the conditions of obtaining their suitable productivity, to develop and realize a continuous, closed (wasteless), technology of cultivating the basic forms of organisms suitable for the closed system, and finally, to obtain quantitative data about the material balance of the organisms in the system. The independent problems raised questions about the effect of the selected biological objects on atmospheric composition, their accompanying microflora, and about the possibilities and ways of utilizing organic wastes that accumulate in the system, including the products of human vital activity. The latter question is an independent BLSS problem, inasmuch as it limits the degree of closure, which means that it also limits the autonomy of the system.

Of course, far from all of these problems have presently been solved to the necessary degree. Their solution still requires a prolonged period of investigations and the development of the appropriate experimental apparatus. However, we have obtained the possibility of renewing investigations of models of biological human life support systems from more prepared positions as the result

of the solutions already obtained.

The possible schemes of such systems are quite uniform. The basis of the system is the plant element, whose photosynthesis should lead to the formation of a biomass which is maximally suitable for use as human food or animal feed, besides regenerating the atmosphere, with a minimum amount of unconsummated waste. The latter requirement significantly limits the choice of the species/<sup>4</sup> of plants and the composition of the human diet.

Man plays the basic role of the heterotrophic element in gas exchange and in the food chains. However, the requirement for the minimum amount of animal food (which has not yet been uniformly determined) makes it necessary to introduce phytophagous animals into the system which should offer minimum competition to man in consuming the vegetable food biomass, in addition to providing high food productivity. But inasmuch as animals and man cannot use the entire produced plant biomass without leaving a residue, the question of the necessity for a culminating functional element of the system arises -- the element of mineralization of unconsumed organic wastes, including human and animal products of vital activity with their return to the cycle via the plant element, and partly, the animal element. Such is the principle scheme of the BLSS, devolving from the functional organization of natural ecosystems.

The basic complexity in the realization of such a simple scheme is to find the necessary and sufficient degree of species, and primarily, functional variety of the composition of each link necessary for realization of the complicated and ramified network of primarily trophic relationships in a system with a minimum number of "vacant" ecological niches. The completeness of closure of the cycle of substances in the system, its autonomy and stability depend upon this.

A number of models of human BLSS with different biological structures, dimensions, and functional parameters has been created and experimentally investigated in the USSR. We shall initially dwell in greater detail on one of the simplest "man-chlorella-microorganisms" models, which was duplicated and studied in several experiments. A system of microbiological mineralization of urine and devices for dehydrating the biomass of algae and human solid wastes for the purpose of returning the water they contain to the general cycle (figure 1) was included in the makeup of the model, in addition to man and algae.

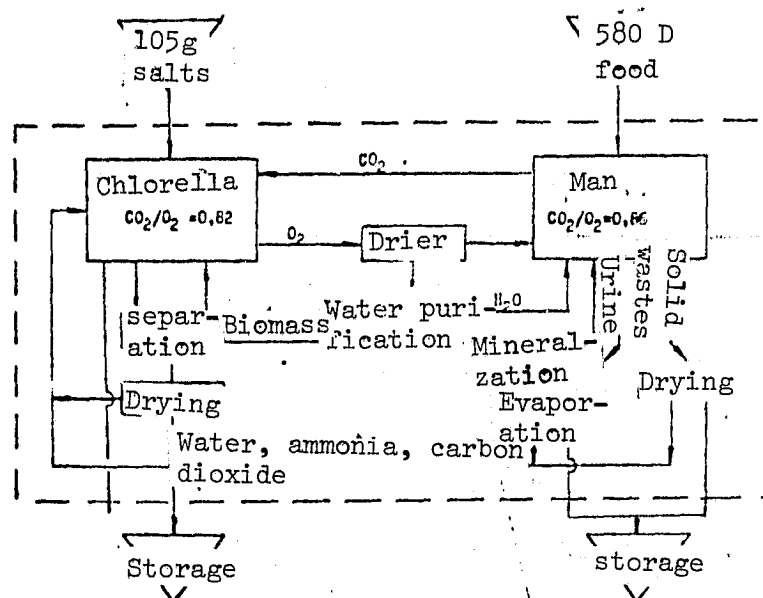


Figure 1. Line diagram of a model of the "man-chlorella-microorganisms" system.

The small air volume needed per man ( $4.5\text{m}^3$ ) and the comparatively small amount of water (50-90 liters, including the algae suspension) was a significant feature of the studied model. Thanks to this, a high rate and multiple of regeneration of substances was achieved in the system, which made it possible to attain five cycles of oxygen regeneration and almost two cycles of regeneration of the amount of water present in one month. The general degree of regeneration of the consumed substances was 79% in our



model (table 1), and was evidently near the maximum for systems with similar functional structures.

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Table 1. DEGREE OF REGENERATION OF SUBSTANCES IN THE "MAN-CHLORELLA-MICROORGANISMS" SYSTEM

Substances	Consumption, g/day	Regenerated in system, g/day	Regeneration in % of consumption
Oxygen	643	643	100
Food	654	50	8
Water	3252	2911	91
Total	4549	3064	79

It became possible for the first time to realize the basic functional principles of biological systems under conditions of a limited space, with a large specific amount of living material, and a maximally simple biocenotic structure by creating such human BLSS models.

Strictly speaking, one cannot discuss a closed cycle of the basic biogenic elements in such models, inasmuch as most of them still enter the system with the stored food and are eliminated from the system as part of the unutilized biomass of algae and other organic wastes. In this connection, one can only consider the closed nature of the cycle of biogenic elements and substances consumed by man to the degree to which the system is closed with respect to food.

The oxygen and carbon dioxide balance is one of the pressing problems of balancing mass exchange in BLSS in the literature. It was established still in the early works that the balance between the atmospheric contents of oxygen and carbon dioxide is disrupted when man or animals are coupled with algae with respect

to gas exchange. This disruption is due to the lack of correspondence between the gas exchange coefficients of the system's elements. We observed precisely the same picture in all experiments. When the system is balanced with respect to oxygen (the productivity of gas exchangers), carbon dioxide accumulates in the air if the gas exchange factor of the algae is below the human (animal) respiratory factor or decreases when (one word cut-off-unknown) ratio of the coefficients. When the atmosphere is /7 balanced relative to oxygen, precisely the same changes were observed in the oxygen content. Analyzing the question made it obvious that one can only avoid disruption of the gas balance when the biochemical composition of the biomass of algae and the assimilated part of the human food ration are equal, which is impossible to achieve in this kind of system.

It seems to us that it is expedient to operate with the accumulation of a carbon dioxide excess when utilizing the oxygen content under conditions of the unavoidable imbalance of gas exchange in the system. In this case, the accumulation of carbon dioxide comprised 5-6% of the rate of its elimination by man. The absorption of this amount of carbon dioxide by the regenerating absorbers poses no significant difficulties in comparison with absorption of the excess of oxygen, if exchange is balanced relative to carbon dioxide. In any case, the problem of gas exchange balancing can be eliminated for such (unknown number of words missing) systems.

The complete regeneration of water was realized in models of this kind by means of the return of water transpired by man, free urine, feces, and the algae biomass to the cycle. All indicated water entered the photosynthetic reactor, and the necessary amount of condensed water vapor was collected from its output for obtaining drinking water. The obtained condensate only required final purification by absorption methods and decontamination by known

physico-chemical methods. A complete water cycle is obviously impossible in such a system due to the entry of chemically bound water as a part of the diet and its elimination from the system as part of the dry fecal residue and the biomass not consumed by the algae. However, these external "inputs" and "outputs" were mutually balanced. Therefore, such a system can operate for an indefinitely long time without (one word missing) supplies of water. The attained degree of closure of the system relative to water (91%) is evidently practically the maximum one for such systems. This made it possible to study the basic functional characteristics of the model, and specifically, the element of algae and their temporal dynamics under conditions of maximum concentrated effect on the algae of their own metabolites, the effect of metabolites of the accompanying microflora, and that of the water soluble products of the microbiological decomposition of urine and human volatile excretions.

The atmospheric content of volatile impurities is an important characteristic of habitability of the atmosphere, formed in the biological life support system. The general result of all gas-forming and gas absorbing activity of the biotic system components could only be studied if any of the devices which absorb these impurities in the system failed, which in a number of cases led to exceeding the maximum permissible concentrations of a number of impurities in the experiments. However, this made it possible to identify the natural atmospheric formation tendencies in the system without any outside interference.

During the investigations it was demonstrated that water-soluble, gaseous impurities that enter the photosynthetic reactors are absorbed by the algae suspension and are found in the atmosphere in trace amounts or are altogether absent (for example, ammonia and hydrogen sulfide). The absorption of these impurities by the algae culture is not only associated with the metabolism of the algae themselves, but also with the activity of the multi-

species association of their accompanying microorganisms.

Poorly soluble impurities (carbon monoxide, methane) initially accumulate in the atmosphere, but their content then stabilizes at a certain level. The equilibrium concentration of carbon monoxide averaged  $20 \text{ mg/m}^3$ , while that of methane averaged  $150\text{-}250 \text{ mg/m}^3$ . Individual excesses of the content of these substances at certain times during the experiments did not lead to prolonged disruption of the established equilibrium, which indicates the presence of mechanisms binding them in the system when their atmospheric concentration increases. As a result, one can see that new possibilities of biological purification of the atmosphere of volatile impurities are revealed when a non-sterile algae culture is used in the BLSS, which can significantly reduce requirements made on the weight and size of filters for removing individual atmospheric impurities and can also preserve possible useful biologically active substances in the regenerated air. It is possible that one can influence the level of the equilibrium concentration of harmful substances in the atmosphere by including specific forms of microorganisms as part of the biocenosis of the algae reactor. /9

One of the basic results of investigating models of this type is their identified capacity for prolonged, stable operation with the developed technology and methods of regulation, as well as their low requirement for control. During a month of operation of the models, no other signs of fundamental instability besides the noted disruption of the oxygen and carbon dioxide balance were noted, on the basis of which one could judge their maximum lifetime. All functional characteristics stabilized at a certain level either immediately after the experiments began or no tendencies toward directional changes were detected following the transitional processes. 15-fold atmospheric regeneration carried out in the system over a month evidently reliably supports the conclusion of

steadiness of processes in the investigated models, taking into account that operating stability of the system is characterized more by the number of regeneration cycles that take place in it than by the absolute operating duration in the experiment.

Steadiness of the system was chiefly due to steadiness of the primary functional characteristics of the algae culture, with whose aid the basic volume of mass exchange in the system took place. Among these characteristics, we have identified both direct (productivity, gas exchange, composition of the biomass, consumption of mineral elements), and indirect characteristics which appear in the parameters of the habitation medium (pH of the medium, its concentration of biogenic elements, the content of noncellular organic material, the population and dynamics of accompanying microflora). Directional changes were not identified with fluctuations near the average value characteristic of these parameters. All of this ensured a stable age structure of the algae population and stable performance of algae functions in the system.

It is important to note that when there were emergency deviations of cultivation conditions from the assigned optimum values during the experiments, no irreversible consequences for the algae culture were noted. When the cells were partly damaged (for example, as the result of overheating of the suspension), the algae culture functioned in the autorecovery regime thanks to the most stable autogenetic state in this case, without additional seeding with the reserve inoculation material. Similar instances, and still more -- the fact of continuous exploitation of precisely the same chlorella strain for at least 15 years -- also resolve the doubts relative to the possible genetic instability of the population of organisms with a short reproductive cycle. Evidently, the organisms are protected by mechanisms of stabilizing selection under conditions of stable cultivation parameters.

The obtained data prompted us to base the understanding of stability of biological systems on their hierarchical structure. This makes it possible to identify the role of specific mechanisms of ensuring stable functioning of the system, which are realized differently at different levels of biological organization: ontogenetic, population, and biocenotic. The classification of phenomena of stability of systems on the basis of known levels of biological organization is evidently the most universal and natural one and can therefore facilitate the further planned study of the problem of human BCSS, which is only beginning to be developed.

The stable operation and the achieved degree of regeneration /11 of substances in the given model with its extremely simple biocenotic structure was ensured to a great extent by the polyfunctional nature of the algae element which, together with the accompanying microflora, performed a number of side functions besides atmospheric regeneration, including performance of the main function during regeneration of water from urine and moisture-containing wastes. The combination of the algae system with the water purification devices that have already been developed makes it possible to reduce the variable component weight of the system to the weights of food supplies, mineral salts, and sorbents.

Additionally, the algae played the role of hydrobiological filter for purifying the atmosphere of water-soluble impurities, which were not only absorbed in the aqueous medium, but were also utilized by the algae and microorganisms. The capacity of the algae culture relative to the water-soluble impurities which pollute the atmosphere significantly exceeds the demand of the system, although its limits have not been finally clarified. In any case, the absorption of ammonia (which is the source of mineral nitrogen for the algae) exceeds the possible rate of its liberation when the urine is completely decomposed.

The chlorella-based system evidently has this volume of functions because it is the arena of the effect of a complex association of algae and accompanying heterotrophic microorganisms, which is characterized by relatively closed trophic links. In this multifunctionality of the algae-based photoautotrophic element one can see its advantage at the first stages of investigating the simplest systems over the terrestrial phytocenoses, which could not perform all of the indicated functions.

As a final conclusion drawn from analyzing the studied model, it seems to us that the model is suitable as the basis of an independent version of the BLSS when limited goals can be set for it--regeneration of the atmosphere and water.

Other forms of algae besides chlorella were also investigated /12 for systems that have the broader scope of the function of food regeneration. It is a fact that the limited possibility of including the chlorella biomass in the human diet is significantly due to its excessive protein content and its carbohydrate deficiency. When we were searching for other strains, we proceeded from the premise that one might find species with a more balanced composition of the biomass with respect to the human diet among representatives of the remote systematic groups. The results of investigating two new algae forms are given in table 2, in comparison with chlorella.

TABLE 2: BIOMASS COMPOSITION OF DIFFERENT ALGAE UNDER NORMAL CONDITIONS OF MINERAL NUTRITION (IN PERCENTAGE OF DRY WEIGHT)

Forms of algae	Proteins	Carbohydrates	Lipids
Chlorella	52.4 $\pm$ 1.8	17.4 $\pm$ 2.4	21.8 $\pm$ 1.8
Chlamydomona	38.2 $\pm$ 2.2	43.3 $\pm$ 2.1	16.6 $\pm$ 1.1
Spirulina	56.9 $\pm$ 4.5	22.3 $\pm$ 1.9	13.9 $\pm$ 2.4

It is evident from the table that the chlamydomona biomass (Chl. reinhardtii) contains nearly three times more carbohydrates, in comparison with chlorella, with a corresponding decrease in the amounts of protein and lipids. The proportion of total assimilable carbohydrates is somewhat higher in chlamydomona, to the same point. The total productivity of these algae forms is practically identical. All this makes it possible to count on the possibility of at least doubling the algae proportion in the diet, and thereby to expand the range of their use in BLSS. With respect to the spirillum itself, then a significant excess of protein in its biomass makes it unpromising as food, in comparison with the other investigated forms.

After obtaining stable results with BLSS models based on one-celled algae, models were created in the USSR which include (the higher) plants. One of these, the most perfect, was created at the Institute of Physics of the Siberian Department of the Academy of Sciences of the USSR (I.A. Terskov, Gitel'zon, G. M. Lisovsky et al.). Its diagram is shown in figure 2.

This model differed from the earlier examined IMBP MZ SSSR models because it was significantly larger ( $315 \text{ m}^3$ ) and had more crew members (3 people). The model was placed in a hermetically sealed chamber which consisted of four identical compartments with an area of  $31 \text{ m}^2$ . A greenhouse with wheat plantings in an area of  $20.4 \text{ m}^2$  is in the first of them (1). The other (2) contains a greenhouse with plantings of vegetables with the same planted area of  $20.4 \text{ m}^2$ . The assortment of vegetables included beets, turnips, radishes, cucumbers, leaf cabbage green onions, fennel, and (word missing) .

Still another compartment (3) was designed with kitchen, toilet, and three individual cabins for rest for the crew. Photosynthetic chlorella-based gas exchangers were installed in the



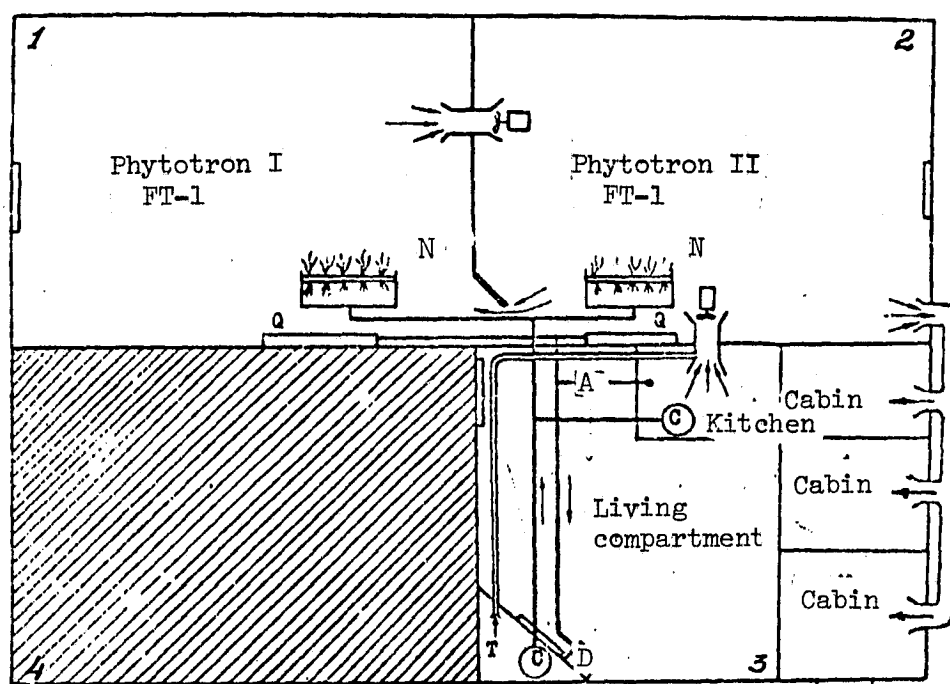


Figure 2. Functional diagram of the "man-higher plants" system model. Q - greenhouse transpiration water condensate collector. A - final drinking water sorbtion purification assembly; D - Container for storing and boiling sanitary-household water; T - toilet and shower; C - waste water collector in toilet and kitchen; N - nutrient medium for wheat.

The arrows designate the flow direction of liquid and gas.

fourth compartment (the shaded area in figure 2).

This model was investigated in three functional-structural versions for six months, with two months of investigation spent on each of the versions. The first version was a "man-higher plants" model in which the algae element did not participate. This is in fact the version that is shown in figure 2. The combination cultivation of algae and wheat plantings was provided in the second version and that of algae and vegetables in the third version.

Inasmuch as the higher plant element was the basic new one in

this model, then we shall dwell on the first version of the "man-higher plants" model, whose diagram is also given in figure 2. Because the algae biomass was not used in the human diet in the other versions, then it is namely this version of the model that is most interesting from the viewpoint of evaluating the possibility of increasing the degree of closure of the system relative to food obtained from the higher plants.

The basic conditions of plant cultivation were the following: continuous illumination with an intensity up to  $145 \text{ w/m}^2$  in the range of photosynthetically active radiation. Air temperature was  $22-25^\circ \text{ C}$ , relative humidity was 72-78%, and the air carbon dioxide content ranged from 2 to 1.5%. Correction of the plants' nutrient solution relative to pH and mineral elements was carried out 1-2 times per day by the crew.

The harvest of the basic crop in the phytocenosis - wheat - over the vegetation period (63 days) was  $3182 \text{ g/m}^2$  of the total dry biomass with  $1118 \text{ g}$  per  $1 \text{ m}^2$  of grain harvest. /15

Daily productivity of the edible biomass of the entire vegetable crop was  $17.7 \text{ g/m}^2$  per day in wheat, and ranged from 21.3 to  $4.1 \text{ g/m}^2$  per day in the vegetables, respectively, for carrots and fennel.

The total proportion of edible biomass for the entire plant element comprised about 32%, which shows the existence of large reserves for increasing this indicator on the pathway of choosing and selecting the most effective plant forms according to the indicator of the maximum edible proportion of biomass with the necessary biochemical composition,

The primary result of investigating this model was obtaining the possibility of increasing the degree of closure of the BLSS

relative to wheat from 8% in the previous models based on algae to 20%. It is understandable that the proportion of vegetable food in the human diet is significantly greater, which demonstrates the possibility of further improving the species and planting structure of the higher plants. In our models employing the higher plants, the possibility of increasing the degree of food utilization of the biomass of higher plants by consuming juices prepared from their unconsumed waste products (roots, beet tops, stems) was shown, which increases the degree of closure of the vegetable element relative to food with precisely the same species and planting structure.

With respect to the other versions of this model ("man-algae-wheat", or "man-algae-vegetables"), then a number of effects of the incompatibility of higher plants with chlorella was identified during their investigation which did not make it possible to study the functional characteristics of these versions. However, it is important that subsequent investigations demonstrated the non-fundamental nature of the detected incompatibility, which proved to be the result of keeping the gathered algae harvest in the common atmosphere of the system at room temperature without illumination.

Possibly, the most interesting result of investigations of /16 this model for our time is related to determining the time spent on servicing the model, inasmuch as the crew serviced the model with the consultation of specialists who were outside the system. Of course, these are only approximate data and not only reflect the system's requirement for monitoring and control, but also the imperfection of the employed methods and the control apparatus. It is still important to note expenditures of crew labor on controlling the given BLSS model comprised about 10% of the duration of the experiment even under these conditions.

It is still not possible for us to present materials on the

experimental study of functional characteristics of the animal element. We have still not investigated such characteristics.

However, it is interesting in this regard to discuss even certain preliminary concepts dealing with this element, which greatly limits the BLSS. Such concepts show that one should prefer the principle of not directly consuming the biomass of animals at the first stages of creating this element, but so-called remote production (milk, eggs). The ideas for obtaining such products and the technology of storing and utilizing such products under the limited conditions of spacecraft force one to give preference to the egg production of poultry.

If one makes such a choice, then quail should be used according to specific egg productivity (per unit of mass of the bird and feed used for it). We therefore assume that the first version of the heterotrophic element in our models will be a quail flock. This is precisely why we and specialists from Czechoslovakia have planned a study of the possibility of incubating quail eggs under weightless conditions aboard a biological satellite in 1979.

In this connection, the perspective of using maggots to utilize the products of human vital activity and of using other unconsumed organic wastes by converting them into a highly effective poultry feed is being examined. All of this should increase the /17 functional variety of the system with respect to extremely significant aspects of realizing its cycle of substances, and therefore should increase both its autonomy and stability.

Such are the basic results of investigations of biological human life support systems that have been carried out in the USSR over approximately the last ten years.

In concluding the presented materials that deal with the results of investigating BLSS in the USSR, it is interesting to discuss new factors which have stimulated us to continue work on this problem even after general interest in it sharply decreased. We have primarily proceeded from the fundamental advantages of BLSS, which make (one word missing) systems the inevitable future of cosmonautics for the period of man's actual conquest of the resources of space and the closest planets.

The first of these advantages -- the stability and reliability of BLSS -- devolves from the capability of biological systems for self-regulation, self-organization, and adaptive behavior. This capability appears differently and to varying degrees at different levels of biological organization, from the ontogenetic to the biocenotic; but this is the greater, the higher this level, and consequently, the higher the functional-structural organization of the system. This blends with the known ideas of the stability of ecosystems as functions of their variety, although the idea of (note: word(s) missing here) species variety (for increasing the stability of the system) is probably more correctly related not to the simple number of species, but to the number of their significant metabolic functions in the system.

Another principal advantage of the BLSS devolves from the generally known fact of the adaptive evolution of terrestrial organisms, as the result of which their modern requirements for habitation environmental factors developed. Adaptive evolution on the Earth ensured a general relationship and mutual interdependency in living nature and its integrity and unity as a system, which is manifested in its functional closure.

The numberless amount of evolutionary-generated links of organisms with the environment (with respect to their basic content of trophic ones) is not subject to description due to the enormous incompleteness of our knowledge. One can only attempt to divide these

links into categories of "vital necessity" according to the length of the characteristic time of appearance of disorders of these links, for example:

Respiratory gases	Minutes	$(3 \cdot 10^{-2} \text{ hr.})$
Water	Several days	$(7 \cdot 10^1 \text{ hrs.})$
Food	Several weeks	$(5 \cdot 10^2 \text{ hrs.})$
Vitamins	Several months	$(2 \cdot 10^3 \text{ hrs.})$

Obviously, these categories of links are vitally, absolutely necessary, and are therefore inevitably the most studied (with respect to the time of manifestation of disorders, these do not exceed the limits of 1% of the length of a human generation). Other, less studied links which control the age structure of the population, realize interpopulational regulatory processes, and others whose characteristic time is commensurate with the life time of generations or even exceeds it several times, for example, in mechanisms of realizing the so-called population (one word missing) also exist in nature. Finally, it is also logical to assume the presence of such categories of links as appear only in a span of time which exceeds the length of a generation by orders of magnitude. One should probably classify the links which are manifested by processes of succession in the biocenoses here.

If one thinks that all these links are realized through environmental habitation factors, then one can imagine the degree of incompleteness of our knowledge relative to this environment, and which is limited to concepts about the elementary composition of atmospheric respiratory gases and the biochemical composition of the diet (with the) assortment of vitamins and other biologically active substances whose list annually increases and which are now known. The fact of adaptive evolution on the Earth leads to the empirical (fact) that the terrestrial environment of organisms is a priori adequate to the biological requirements, both individual, and in the generations. And (word missing), the reduction of more

or less significant links of the organisms (with the environment) inevitably entails the loss of this adequacy. The question only consists in which category of the characteristic time of appearance these links are classified, and consequently, how long this can be safe for an organism, a population, or a biocenosis.

In connection with the presented ideas about the fundamental characteristics and advantages of biological life support systems in comparison with the nonbiological ones, it is appropriate to note that the evaluation of their promise cannot subsequently be constructed on the basis of their gravimetric, dimensional and other (physical) characteristics. In fact, such an approach led earlier to an unjustified delay in developing BLSS which it is already difficult to compensate for. In estimating the promise of BLSS, one should take into account the completeness of their (one word missing) in supporting human metabolic requirements and parameters of the habitation environment, their stability and reliability, and particularly, their capacity to form a biologically adequate environment. (One word missing) these criteria do not have adequate points of comparison with nonbiological systems and therefore a comparison of their mechanical parameters is meaningless, except for the possibility of establishing which is lighter and which is heavier. The problem of the human BLSS raises a number of fundamental ecological questions whose answers cannot be derived from the data of general ecology. (For example), the establishment of the critical size of the system, when it (becomes) quite stable and reliable on the scale of the necessary (one word missing) of its operation, the establishment of the most "compact" ratio of living to non-living material in the system, and a number of other questions. Technical problems that are also expediently discussed on a level with the biological ones also deserve (intense) attention. In recent years, a rapid increase in the amount of literature in the field of mathematical analysis of biological systems has been observed in connection with the development of the "man

and environment" problem. Among these works for (unknown number of words missing) investigations devoted to their stability. Here, I shall cite (one word missing) survey of investigations in this field, kindly provided me (unknown number of words missing) by V. V. Verigo: a noticeable role in the problem of designing reliable and stable BLSS which have (one word missing) effectiveness and meet the given requirements is played by methods of mathematically modeling them, which are essentially a partial application of the mathematical modeling them, which are essentially a partial application of the mathematical modeling of ecological systems, which has long and extensively developed in the USSR and the USA. Among the investigations of this type performed recently in (word missing), one can point out the cycle of works of I. S. Abrosova and his colleagues, devoted to (word missing) of regulation of the species composition of the trophic level of one celled organisms. In these works, a theory of the development of a continuous (unknown number of words missing) of microorganisms which grow on a multicomponent nutrient medium was developed. The conditions of compatibility of competing species were found in these works and the trophic properties of the medium which permit the realization of this compatibility are indicated. The authors also demonstrated the possibility of controlling the species (one word missing) and the relative ratios of biomasses of the organisms in the association (unknown number of words missing) variations of the rates of supply of nutrients.

One of the most important problems of creating artificial ecological systems, for whose investigation the use of the approach methods of mathematical biology is particularly expedient, is the selection of the structure and characteristics of the system which guarantee its stability. The problem of creating "minimal" BLSS with a minimum number of included species and which are simultaneously stable figures among the six fundamental problems of mathematical biology and medicine which, according to the known estimate,



must be solved before the year 2,000. The prevalent opinion that (one word missing) of the ecosystem ensures its stability, which is partly (one word missing) in the presentation of the above mentioned problem of NASA estimates and our (word missing) discussions. However, in reality, the situation is (one word missing) complex. /21

One of the most exhaustive modern investigations is in the book by Yu. M. Svirezhev and D. O. Logofet, where (unknown number of words missing) stability of isolated populations and classical (unknown number of words missing) systems, examine questions of the stability of associations which include several species, the stability of trophic chains, spatially distributed ecosystems, and associations with overlapping of ecological species; the extreme properties of ecosystems, and a number of other problems. (One or more words missing) showed the relationship of the earlier suggested entropic measures of species variety of the association as characteristics of its stability.

The basic cause of this is the adequacy of the entropic (one word missing) for ensembles consisting of weakly interacting objects. With respect to the associations themselves, then they usually include dominant species which perform the basic function in processing the material and energy. The hierarchical structure of biological associations is determined to a great extent by the characteristics of the interspecies relationships, i.e., by the strong interactions. This opinion of the authors can be compared with an approach which, with the aid of the concept of "associated stability", which demonstrates the stability of a number of ecosystems, identifies subblocks within them, whose intensity of interaction can weaken up to complete disappearance. However, interactions within the subblocks remain significantly strong.

The authors' conclusions pertain to the fact that no uniform relationship exists between the complexity and the stability of

ecosystems: examples exist of positive and negative correlations between these characteristics. We note that the deceptive clarity of the apparently, intuitively clear concept of "stability of the ecosystem" vanishes when the problem is mathematically formalized.

The possibility of a uniform interpretation of this concept /22 engenders nonuniformity of the mathematical equivalents (Lyapunov stability, (unknown number of words missing) etc.). It is possible that the concept of "hierarchical stability", which was introduced by Yu. M. Svirezhev and takes into account the natural hierarchical structure of characteristic times of the individual blocks(levels) of the system will prove fruitful.

At present, the mathematical modeling of ecosystems (1 word unknown) a successfully developing trend which seems to be a useful tool in the development of the theoretical aspects of designing BLSS and of making quantitative estimates of their effectiveness.

The report does not examine the trends and prospects of future investigations. This can be done when discussing this material.

#### References

- \*, I.S., V. G. Gubanov, B. G. Kovrov. 1976 "The Theoretical Investigation of Functioning of Closed Ecological Systems." "Izvestiye SO AN SSSR", Biological series, no. 15, Issue 3.
- \* I. S., B. G. Kovrov. 1977 "Analiz vidovoy struktury troficheskogo urovnya" ("Analysis of the Species Structure of the Trophic Level") Novosibirsk, Nauka".
- \*, I.S., 1979 The Closed Ecosystem and the Chemostat Analogy and Examples of Analysis, "Zhurnal obshchey biologii", no. 2.
- Svirezhev, Yu. M. D. O. Logofet. 1978 "Ustoychivost' biologicheskikh soobshchestv" ("The Stability of Biological Associations") Moscow, "Nauka".
- \* illegible in foreign text.

- Svirezhev Yu. M. 1974 "The Hierarchical Stability of Biological Associations". V. kn. "Matematicheskoye modelirovaniye morskikh ekosistem" ("In the book" "Mathematical Modeling of Marine Ecosystems") Kiev, "Naukova dumka", 44-46.
- \* , Ye.Ya. 1975 "Biological Life Support Systems". V. Kn. Osnovy kosmicheskoy biologii i meditsiny. ("In the book: "Fundamentals of Space Biology and Medicine"), Moscow, vol. 3, "Nauka", 277-313.

\*Illegible in foreign text.